PERMEABILITY OF SILICA FUME AND POLYPROPYLENE FIBERS REINFORCED CONCRETES

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ABSTRACT

The target of the presented study is to investigate the permeability of polypropylene-fiber-reinforced concretes, with and without silica fume (SF), using various mix proportions. This effort was made to clarify the contradicting published literature data.

The considered fiber volume fractions were 0.1 %, and 0.5%. Silica fume was used as 10% replacement of cement weight. Different water and air curing condition were carried out to study their effect on the permeability of concrete. Cement contents of 350 kg/m^3 or 450 kg/m^3 were utilized. Water/cement ratios of 0.30, 0.40, and 0.50 were considered in the program. Results showed that the incorporation of polypropylene fibers had varying effects on the permeability of concrete depending on cementitious material content, w/c ratio and curing regime.

Silica Fume, as generally recognized, improved both concrete strength and impermeability. Polypropylene fiber (PPF) did not, unconditionally, improve concrete resistance to flow. When cementitious material content was increased and w/c ratio was lowered PPF enhanced concrete impermeability. Otherwise, PPF did not improve concrete impermeability. It is also noticed that polypropylene fibers improved the performance of concretes subjected to insufficient curing periods, compared to similar mixes without fibers.

KEYWORDS: Polypropylene fibers – Concrete – Silica Fume – ISAT – Permeability - Cracking.

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نفاذية الخرسانة المحتوية على غبار السيليكا وألياف البولي بروبيلين

الهدف من هذا البحث هو دراسة تأثير إضافة كل من ألياف البولي بروبيلين وغبار السيليكا على نفاذية الخرسانة ، وكذلك تأثير احتواء الخرسانة على ألياف البولي بروبيلين وغبار السيلكا معاً ، وذلك لنسب الخلط المختلفة. وقد تمت هذه الدراسة نظراً لتضارب نتائج الأبحاث المنشورة عن تأثير استخدام المواد المذكورة في الخلطة الخرسانية.

خلال هذا البحث تم استخدام خلطات خرسانية بمحتوى أسمنت للمتر المكعب يساوي 350 و 450 كجم. كما تم اختبار خلطات لها نسب ماء/أسمنت مختلفة تراوحت بين 0.3 إلى 0.5. اضيف غبار السيلكا للخلطات بنسبة 10% من وزن الأسمنت وبالإحلال المباشر كما استخدمت ألياف البولي بروبيلين بنسب حجمية تساوي 0.1% و 0.5%. ولدراسة تأثير المعالجة ، تم تطبيق ثلاث برامج مختلفة بداية بالمعالجة في الهواء إلى المعالجة بالماء.

بينت النتائج أن غبار السيلكا يحسن مقاومة الخرسانة للضغط وسريان المياه ، كما هو متفق عليه بالأبحاث المنشورة. أما بالنسبة لتأثير ألياف البولي بروبيلين على الخرسانة ، فقد بينت النتائج أن تأثيرها يعتمد على محتوى الأسمنت ونسبة الماء إلى الأسمنت (م/س) بالخلطة. فكلما زاد محتوى الأسمنت وقل م/س ، كان تأثير الألياف مفيدا ، والعكس بالعكس. بينت النتائج أيضاً أن استخدام الألياف يكون مفيداً حال عدم معالجة الخرسانة بصورة جيدة.

1. INTRODUCTION

When plain concrete is gradually loaded, it deforms elastically causing micro cracking, localized macro cracking, and finally it is fractured. Therefore, fibers are used in fiber-reinforced-concrete to improve its post cracking ductility and toughness [1, 2].

Randomly oriented short fibers, in cement based materials, are generally recognized to retard crack propagation, especially in aggressive environments [3, 4, 5]. Reduction in concrete plastic shrinkage and drying shrinkage is also noticed as a benefit of using fibers in concrete [6, 7, 8, 9]. One major application of fibers in concrete is to improve resistance of concrete to shrinkage cracking in restrained members such as slabs and pavements [8, 10, 11, 12, 13]. Results indicate that while polypropylene fibers, in general, are effective in controlling plastic shrinkage cracking in concrete, a finer fiber is more effective than a coarser one, and a longer fiber is more effective than a shorter one [14]. The improvement in concrete properties due to the addition of fibers is dependant upon concrete matrix strength, and aggregate size, and fiber characteristics such as type, modulus of elasticity, aspect ratio, strength, surface bonding characteristics, content, and orientation [2, 6, 11]. It is also reported that the addition of polypropylene (PP) fibers to concrete resist spalling of concrete cover in regular and different fire conditions where the existence of fibers mitigate the internal temperature elevation [3, 15, 16, 17, 18, 19].

The most commonly used synthetic fibers in concrete pavements are made of fibrillated polypropylene. They are normally used in concrete at a rate of at least 0.1% by volume [2, 8, 11]. Polypropylene fibers are chemically inert and have relatively high tensile strength and an acceptable resistance to temperature (165°C average melting point and l30°C average for highest safe temperature). However, the disadvantage of polypropylene fibers is their low elastic modulus [2].

Silica Fume (SF) is also used in concrete to improve its durability and strength. In aggressive sulphate environments, SF is used as an additive or by replacement of cement. Also, there are other properties that are favorably affected by the incorporation of silica fume, including: modulus of elasticity, drying shrinkage, bonding between concrete and steel, and resistance to reinforcing steel corrosion and sulfate attack due to low permeability to water and chloride ions. On the other hand, some unfavorable properties are associated with the addition of silica fume to concrete, such as loss of slump and reduction in ductility [20, 21].

The use of silica fume concrete reinforced with fibrillated polypropylene fibers thus warrants investigation. The addition of silica fume improves fiber dispersion in the cementitious matrix, causing a significant reduction in the permeability of the polypropylene fiber reinforced concrete. [22, 23, 24]. By achieving a decreased permeability and increased impact and cracking resistance, a material with superior properties for overlay applications can be achieved.

Nevertheless, published research show a contradicting performance of PPF concrete as a result of the limited studied mix proportions and exposure conditions. The decrease in permeability is reported by some researchers for using polypropylene fibers in concrete. This enhancement was attributed to the improvement of cement hydration, reduction on separation of aggregate, and reduction of the flow of water through concrete [5, 11, 25, 26, 27]. On the other hand, other reports state that using PPF in concrete has no effect or even it increases the permeability of the investigated concretes [23, 28, 29]. Additionally, the available literature indicated that using pozzolans (silica fume or fly ash) has its effective role in reducing the permeability of concrete in the existence of Polypropylene fibers [23, 24].

2. RESEARCH OBJECTIVES

This paper studies the role of adding silica fume and polypropylene fibers to improve the durability of concrete. The results presented in this paper will provide more information on the behaviour of polypropylene fibers in concrete. The study aimed to investigate the effect of the following parameters on the permeability of PPF concrete:

- Curing method
- Fiber content
- Cement content
- Water / cement (w/c) ratio
- Combining PPF with silica fume in concrete
- Rate of water flow through concrete surface

3. MATERIALS AND CONCRETE MIXTURES

To study the effect of PPF with/without silica fume on concrete permeability, several Ordinary Portland Cement (OPC), OPC-polypropylene fiber, OPC-Silica Fume, and OPC-polypropylene-Silica Fume concrete mixes are used. The following materials are used in this study:

- **Cement**: OPC in accordance with Egyptian Standards ESS 4756:2006 type 42.5 N, which is similar to the ASTM Type I Portland cement, with a specific gravity of 3.14 and a specific surface area of 378 m^2/kg;
- **Fine Aggregates**: Natural river sand having a fineness modulus of 3.18, a specific gravity of 2.60 and absorption of 0.55 percent;
- **Coarse Aggregates**: Dolomite with maximum grain size of 19 mm, a specific gravity of 2.61, Impact modulus of 17% and absorption of 1.3 percent;
- **Superplasticizer**: Ligno sulphonate based super plasticizer complying with ASTM C 494 type F;
- **Silica fume**: Locally produced Silica Fume with a minimum silicate content of 95% and an average specific surface area of 16 m^2/g;

- **Polypropylene fibers**: Fibrillated polypropylene fibers having a specific gravity of 0.91, with a tensile strength ranging between 550 and 760 MPa, a modulus of elasticity of 3,500 MPa, and a melting point of 162°C. Fiber lengths are graded between 12 mm and 19 mm. The fibers are virgin homopolymer and comply with ASTM C-1116 type III.

The experimental program includes six control concrete mixes according to the cement content and water/cement ratio. Table 1 shows mix constituents of the used group types.

Each of the six mixes is modified by adding SF and PPF as follows;

1- Addition of 10% SF, by direct replacement of cement weight.
2- Modifying the mix by adding 0.1% PPF of concrete volume.
3- Providing the mix with 0.5% PPF by volume.
4- Adding both 10% SF and 0.1% PPF (combining case 1 and case 2).
5- Combination of case 1 and case 3.

All mixes are water cured for 28 days, then tested. Another two sets of the samples are prepared to study the effect of curing on concrete permeability. The first set is cured at water for 3 days then left at laboratory air for 25 days; the second is cured in laboratory air for 28 days. Permeability tests are performed using the ISAT flow test to BS 1881: Part 5.

5. RESULTS AND ANALYSIS

The 7 and 28 day compressive strength results of different mixes are shown in Table 2 and Table 3, for different curing methods. The shown results agree with the commonly accepted behaviour of PPF and SF concretes [2, 20]. The use of SF increased the strength of concrete, while PPF had negligible effect on concrete strength, as shown in Figures 1 and Figure 2.

Table 4 and 5 show the results of the ISAT permeability tests on concrete at the age of 7 and 28 days, cured at different durations. The shown results indicate that;

For water cured concretes (Figure 3 and Figure 4):

Adding SF by 10%, direct replacement of cement weight, improved concrete impermeability. The permeability of concrete, measured by the ISAT flow, was lowered by up to 33% due to the use of SF. The reduction in concrete permeability was dependant upon w/c ratio and cement content of the mix. In lower cement content and lower w/c ratio mixes, the effect of SF appeared to be more evident.

The effect of reinforcing concrete by 0.1% of its volume with PPF depends on the w/c ratio and cement content of the mix. For mixes with 350 kg/m3 cement content and w/c of 0.5 and 0.4, the use of PPF increased concrete permeability. In contrast, for mixes with w/c = 0.3, the utilization of PPF had a beneficial effect on concrete permeability. In mixes, containing 450 kg/m3 cement, permeability improved when w/c was 0.5 and 0.4. Using w/c of 0.3 in higher cement content mixes resulted in increased permeability probably due to poor compactability. This behaviour can be explained by the nature of PPF in concrete. PPF does not chemically bond with cement matrix and therefore, form presumably small channels in concrete body [2]. In concretes with higher w/c and lower cement content, the excess water forms voids and connect the flow channels in concrete body. By lowering w/c and increasing cement content, flow channels through concrete become disconnected and concrete permeability is lowered.

Similar conclusions can be drawn for concretes with 0.5% PPF content. Nonetheless, when w/c of 0.3 is used, the PPF concretes permeability became approximately equal to that of control mixes. The results implied that, the use of PPF by 0.1% had a better effect on concrete permeability that that of 0.5%.

Adding both SF and PPF to concrete mixes, with all the tested w/c ratios, appeared to have a limited effect on concrete permeability, compared to control OPC mixes. Comparing the same results with SF concrete permeability, the SF-PPF concrete did only perform better when w/c of 0.4 was used. This can be attributed to the combined effect of mix's homogeneity, matrix density and compactability. Those aspects were optimized when w/c of 0.4 was used.

<u>For earlier ages and when shorter periods of curing were used;</u>

At the age of 7 days, the ISAT permeability of concrete was higher than that at 28 days of water curing. The reduction in ISAT flow due to age was higher for concretes containing 350 kg/m^3 with w/c equals 0.5. Increasing cement content to 450 kg/m^3 and lower w/c to 0.3, considerably improved the ISAT flow at early age of 7 days.

The effect of improper curing in concrete permeability was notable. Almost all samples cured at laboratory air for 28 days, had higher ISAT flow values than even those cured in water for 7 days. This observation emphasized the importance of prolonged curing of concrete on concrete durability. The deterioration in permeability due to insufficient curing was highest in CF concretes and lowest in OPC-PPF concretes with 0.1% volume ratio. The reduction in concrete resistance to water flow due to insufficient curing was noticed to increase with the increase of cement content and the decrease in w/c ratio.

Using, 3 days of water curing and 25 days of air curing, improved the resistance of concrete to water flow. This enhancement was typically higher in concretes having lower cement content and higher water/cement ratio.

From the results obtained in this research, it can be claimed that the ability of mixes containing PPF to tolerate with inadequate curing are higher than the corresponding mixes without PPF, Figures 5-A, B, C and D.

6. CONCLUSIONS

The following conclusions can be drawn from this study:

1- Using SF in concrete improves both its compressive strength and resistance to water flow.

2- The effect of using PPF in concrete by 0.1 and 0.5 % of its volume depends on the w/c ratio and cement content of the mix. Mixes with higher w/c ratio and lower cement content are adversely affected by the use of PPF.

3- Adding both SF and PPF to concrete mixes, does not appreciably improve concrete permeability, compared to the similar OPC mixes. Comparing the same results with SF concrete permeability, the SF-PPF concrete is affected by the accumulative effect of mix's homogeneity, matrix density and compactability. This effect appears to be optimum when w/c of 0.4 was used.

4- Permeability of concrete is improved with age. The improvement with time is affected by cement content and w/c. Increasing cement content and lowering w/c ratio appreciably improve concrete impermeability at early age of 7 days.

5- Insufficient curing adversely affects concrete permeability and consequently its durability. The deterioration in permeability due to insufficient curing is highest in CF concretes and lowest in OPC-PPF concretes with 0.1% volume ratio. The reduction in concrete resistance to water flow also increases with the increase of cement content and the decrease in w/c ratio.

6- From the results obtained in this research, it can be recommended to use PPF in concretes prone to inadequate curing.

7. ACKNOWLEDGEMENT

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Table 1: Concrete control mix proportions (kg/m^3)

Type	W/C Ratio	Cement Content	Water	Fine Agg.	Coarse Agg.
A1	0.50	350	175	686	1168
A2	0.40	350	140	677	1257
A3	0.30	350	105	681	1311
B1	0.50	450	225	608	1036
B2	0.40	450	180	610	1134
B3	0.30	450	135	615	1176

Table 2 : Compressive strength of concrete mixes with cement content of 350 kg/m^3

Mix Designation	Compressive strength (kg/cm^2)			
	7 Days	28 Days		
	Water curing	Water curing	Water + Air curing	Air curing
A1 : w/c = 0.5				
OPC	223	275	258	271
SF	304	341	279	256
PP.01	241	258	286	255
PP0.5	179	254	275	271
SF+PP0.1	261	336	323	284
SF+PP0.5	270	312	329	336
A1 : w/c = 0.4				
OPC	239	298	315	299
SF	384	400	341	333
PP.01	250	353	387	355
PP0.5	227	301	324	313
SF+PP0.1	376	377	356	288
SF+PP0.5	356	382	365	362
A1 : w/c = 0.3				
OPC	314	312	- - - -	- - - -
SF	383	436	- - - -	- - - -
PP.01	274	257	- - - -	- - - -
PP0.5	198	256	- - - -	- - - -
SF+PP0.1	278	324	- - - -	- - - -
SF+PP0.5	264	283	- - - -	- - - -

Table 3 : Compressive strength of concrete mixes with cement content of 450 kg/m^3

Mix Designation	Compressive strength (kg/cm^2)			
	7 Days	28 Days		
	Water curing	Water curing	Water + Air curing	Air curing
A1 : w/c = 0.5				
OPC	254	316	301	290
SF	283	342	330	312
PP.01	226	310	342	338
PP0.5	304	335	388	323
SF+PP0.1	321	372	353	339
SF+PP0.5	372	419	401	390
A1 : w/c = 0.4				
OPC	267	348	405	399
SF	441	464	452	389
PP.01	346	393	375	325
PP0.5	305	357	331	321
SF+PP0.1	438	475	439	403
SF+PP0.5	402	422	398	369
A1 : w/c = 0.3				
OPC	415	422	- - - -	- - - -
SF	439	444	- - - -	- - - -
PP.01	402	353	- - - -	- - - -
PP0.5	309	353	- - - -	- - - -
SF+PP0.1	399	460	- - - -	- - - -
SF+PP0.5	432	438	- - - -	- - - -

Table 4 : ISAT flow of concrete mixes with cement content of 350 kg/m^3

Mix Designation	2 minutes ISAT flow (ml/m^2/sec)			
	7 Days	28 Days		
	Water curing	Water curing	Water + Air curing	Air curing
A1 : w/c = 0.5				
OPC	0.852	0.6	0.923	1.03
SF	0.445	0.429	0.635	0.639
PP.01	0.607	0.666	0.808	0.74
PP0.5	0.602	0.646	0.857	0.897
SF+PP0.1	0.548	0.567	0.635	0.729
SF+PP0.5	0.636	0.567	0.625	0.661
A1 : w/c = 0.4				
OPC	0.558	0.518	0.696	0.804
SF	0.568	0.518	0.842	1.359
PP.01	0.626	0.587	0.739	0.76
PP0.5	0.79	0.67	0.856	0.902
SF+PP0.1	0.597	0.49	0.667	0.902
SF+PP0.5	0.538	0.44	0.429	0.688
A1 : w/c = 0.3				
OPC	0.442	0.438	- - - -	- - - -
SF	0.401	0.293	- - - -	- - - -
PP.01	0.528	0.38	- - - -	- - - -
PP0.5	0.665	0.49	- - - -	- - - -
SF+PP0.1	0.57	0.421	- - - -	- - - -
SF+PP0.5	0.46	0.54	- - - -	- - - -

Table 5 : ISAT flow of concrete mixes with cement content of 450 kg/m^3

Mix Designation	2 minutes ISAT flow (ml/m^2/sec)			
	7 Days	28 Days		
	Water curing	Water curing	Water + Air curing	Air curing
A1 : w/c = 0.5				
OPC	0.78	0.563	0.715	0.92
SF	0.54	0.51	0.812	1.134
PP.01	1.16	0.636	0.557	0.947
PP0.5	1.08	0.59	0.88	1.141
SF+PP0.1	0.636	0.54	0.651	0.909
SF+PP0.5	0.573	0.87	1.492	1.59
A1 : w/c = 0.4				
OPC	0.66	0.59	0.808	0.953
SF	0.49	0.57	0.95	1.187
PP.01	0.607	0.612	0.838	0.921
PP0.5	0.6	0.519	0.705	1.035
SF+PP0.1	0.565	0.392	0.724	0.755
SF+PP0.5	0.435	0.489	0.795	0.882
A1 : w/c = 0.3				
OPC	0.553	0.508	- - - -	- - - -
SF	0.421	0.42	- - - -	- - - -
PP.01	0.431	0.396	- - - -	- - - -
PP0.5	0.58	0.465	- - - -	- - - -
SF+PP0.1	0.543	0.538	- - - -	- - - -
SF+PP0.5	0.714	0.567	- - - -	- - - -

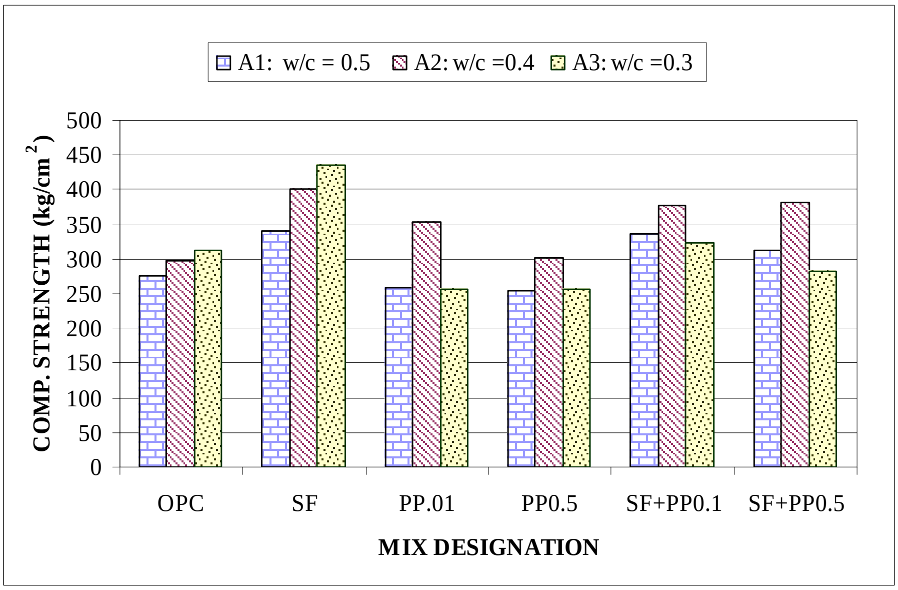


Figure 1: Compressive strength results of concrete mixes containing 350 kg/m^3 cement at the age of 28 days of water curing.

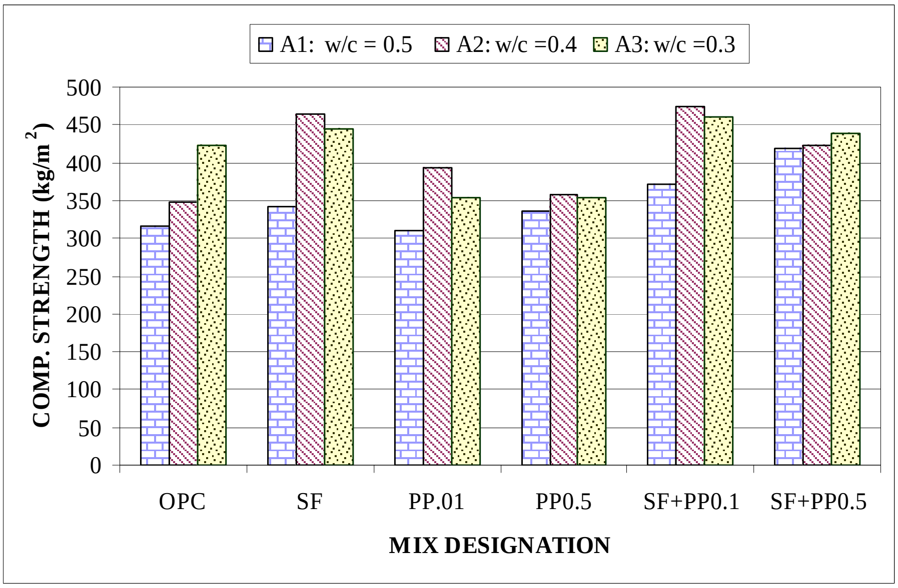


Figure 2: Compressive strength results of concrete mixes with cement content of 450 kg/m^3 at the age of 28 days of water curing.

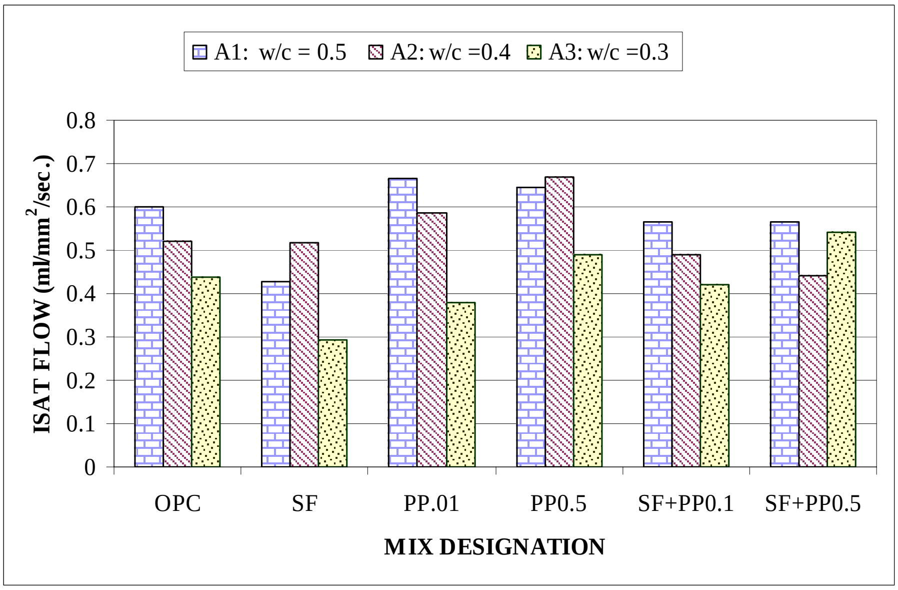


Figure 3: ISAT flow for concrete samples at the age of 28 days of water curing, cement content 350 kg/m^3.

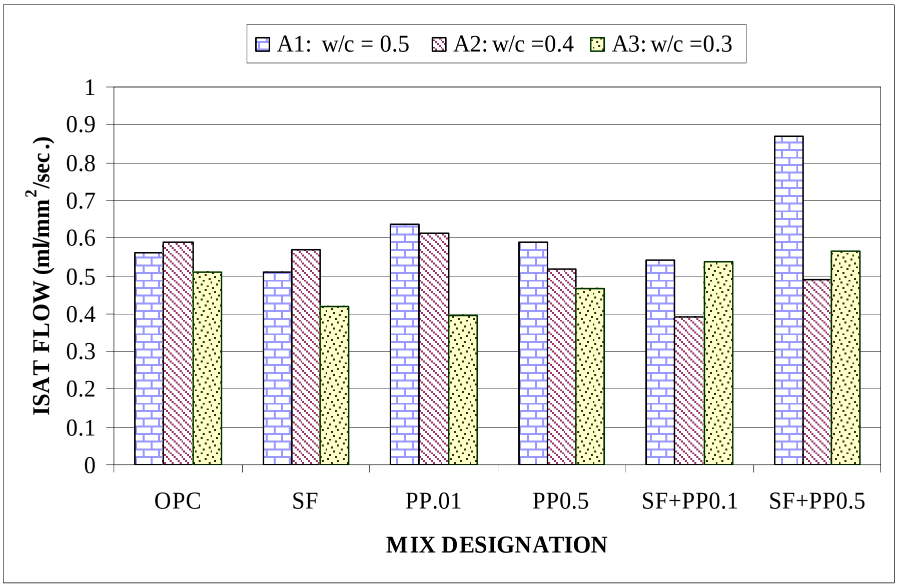
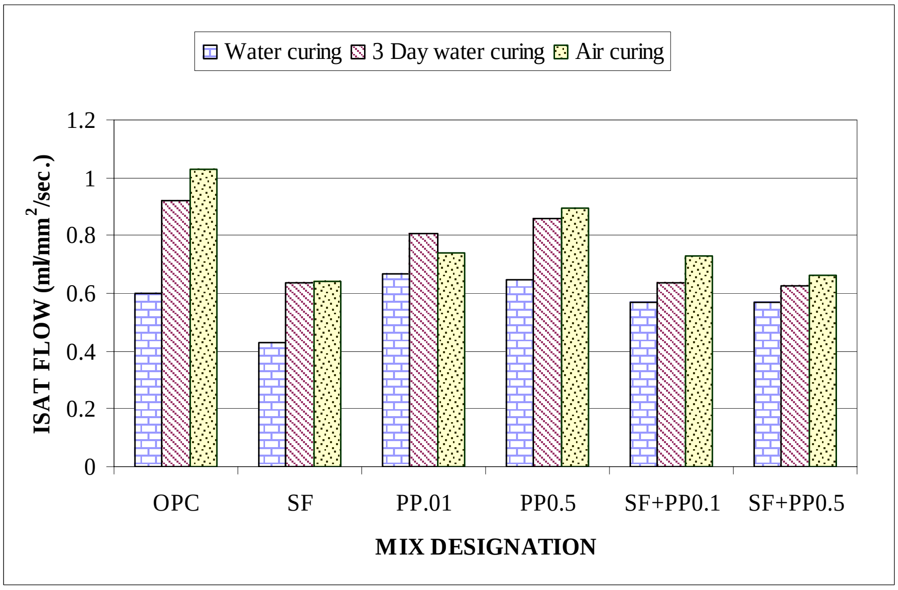
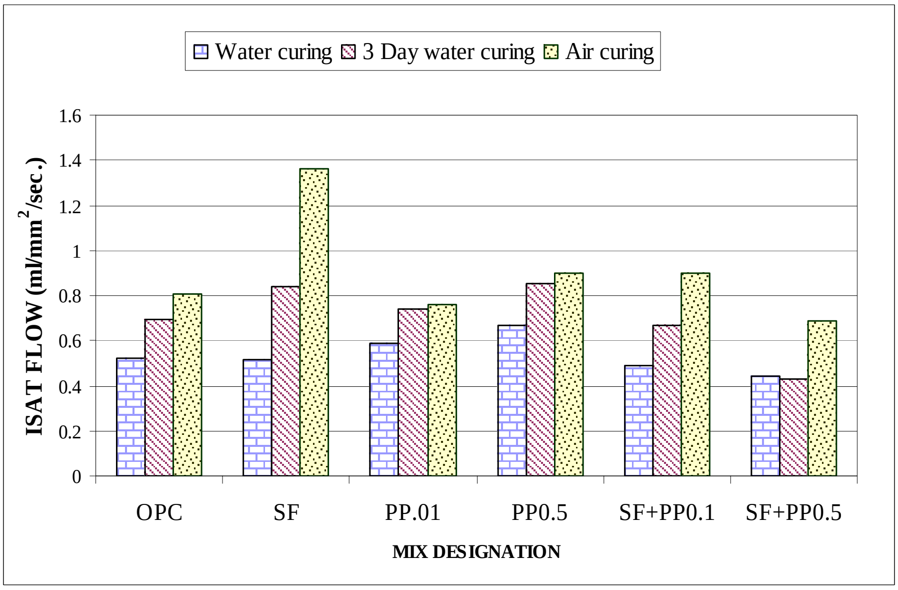


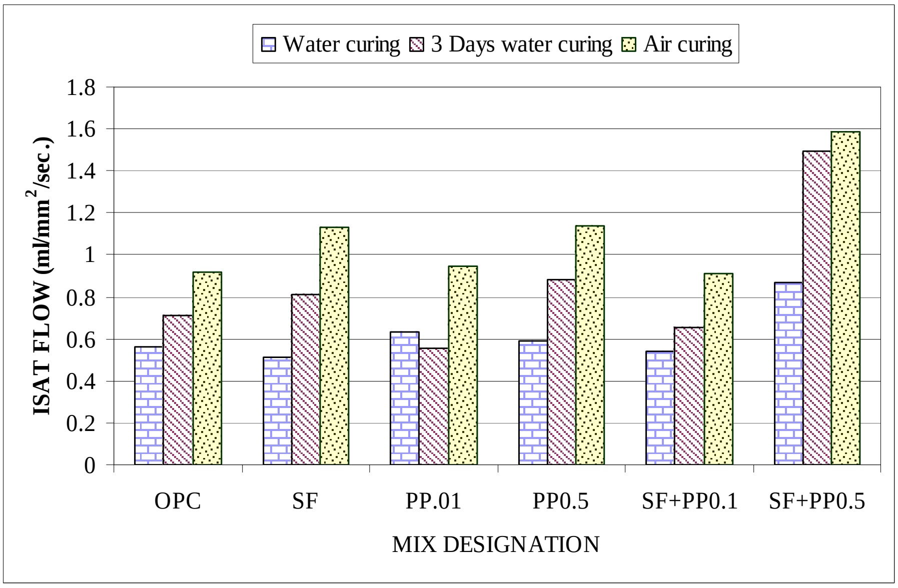
Figure 4: ISAT flow for concrete samples at the age of 28 days of water curing, cement content 450 kg/m^3.



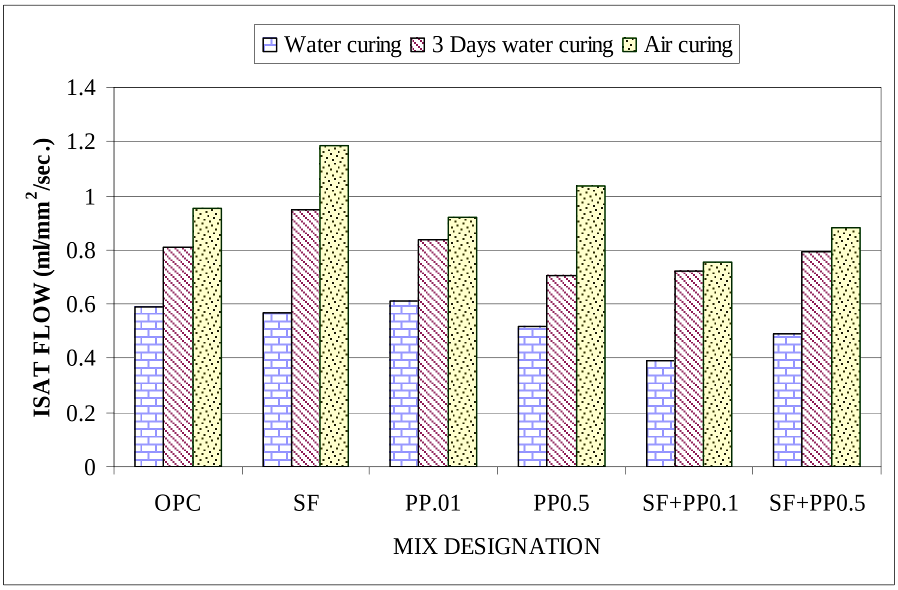
A: 350 kg/m^3 cementitious material – w/c = 0.5



B: 350 kg/m^3 cementitious material – w/c = 0.4



C: 450 kg/m^3 cementitious material – w/c = 0.5



D: 450 kg/m^3 cementitious material – w/c = 0.4

Figure 5: Effect of water curing duration on the permeability of concrete, at the age of 28 days.